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NEW DIGITAL WATTMETER/ WATTHOURMETER BASED ON THE USE OF SLOW AD CONVERTERS

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INTRODUCTION

This paper deals with the problems of measuring electric values in distribution networks (voltage, current, power, energy, power factor, frequency), from the aspect of precision of such measurings and the feasibility of their simple and practical realization. For the realization, we used a slow but highly precise dual-slope A/D converter, a solution which required a test of the stationary state of the observed distribution network. It is understood that the concept of stationary state is to be taken in its relative sense, since it refers to a stationary state over a short period of time (a couple of seconds) necessary to conduct the measuring by the suggested method [1]. However, it is impossible to talk about the stationary state of the whole EES, having in mind all the transition occurrences, non-linearities and different voltage levels at which the measuring can be done.

The confirmed ‘stationary state’ of the observed system opens a possibility to apply a simple measuring concept, to measure the electric values (voltage, current, power, energy), based on the application of the so-called ‘stroboscopic technique (synchronous undersampling)’ , by using slow but highly precise dual-slope A/D converter and high resolution [2]. Taking these facts into consideration, it is obvious that the interval necessary to conduct a correct processing becomes very short, from the point of view of the inertia of a big system such as a distribution network. This has been fully confirmed by the experimental measurings that were conducted. The time required to complete the measurings is about one second [1]. As opposed to the synchronous sampling technique, the measuring conducted here used a much lower sampling frequency, in relation to the one resulting from the Nyquist criterion. That is the reason to use a slow, cheap but highly precise dual-slope A/D converter in the suggested measuring system. The standard dual-slope A/D converter works at the sampling frequency range of 4-96Hz, depending on the input amplitude. In the observed system, the measurings of the voltage and current are taken at the distance that is defined by the expression:

$$t_{sampling} = N \cdot T + \Delta t \qquad (1)$$

where N represents the whole number of periods between the taken measurings of the observed signal, T is the period of the basic harmonic of the observed signal, and Δt is the delay conditioned by the processing in the system. The Δt value is dependent of the harmonic content of the input signal [1]. For this reason, it cannot be specified in advance. The problem of noise (which exists in every real system, due to the process of middle-value calculation in the active power evaluation process) is not a relevant one, since the middle value of the noise equals zero. The possible non-linear distortions in the transition process do not last for long, so they can be left out in the analysis, from the point of view of the length of the measuring period of the suggested digital instrument to be used for measuring the flow of power. Measurings on the distribution network in Yugoslavia, conducted over a period of several minutes did not show relevant changes to the value of the observed signal. The analysis shows that the required inertia can be limited to a period of several seconds.

PRACTICAL REALIZATION

In the practical realization of the proposed digital measuring system, we start from all the premises exposed in the first part of the work. The main processing unit on the plate is the dual-slope A/D converter. For this occasion, we chose the TC530 converter made by the Linear Technology company, as a converter that met the demands of the project. One of the reasons why we chose this circuit was that it was available at the moment. It should be said here that, should this measuring system be introduced in the regular practice, then it would be possible to do a more thorough search and perhaps find a better value-for-the-money solution. TC530 offers the resolution of as many as 16 bits, it also has a serial port, changeable speed of conversion (depending on the chosen resolution), automatic detection of the input signal polarity and its possible overstepping of the allowed range. The conversion is initiated when the RESET input signal is lowered to the low logical level. After the conversion is finished, the data is stored in the output shift register, and the EOC (End of Conversion) signal reports that there is new data available. The converted data (as well as the possible overstepping of the range and the polarity bits) is stored in this output shift register, until the processor completes the reading, or until the next conversion is finished (until this is done, they are at the user's disposal). Since this converter can perform various numbers of conversions per second (for the 16-bit resolution, its integrating time is 66ms), according to the manufacturer's specifications, different values of the outside elements are chosen: R_{int}, C_{int}, C_{ref}, C_{az}. For the 16-bit resolution (the one which is required in this realization), it is necessary to have the resistor R_{int} of 100kOhm, , C_{int}=0.33mF, and C_{ref}= C_{az}=0.22mF, with a possibility to perform 4 conversions per second. For a larger number of conversions at the same resolution (more than 7 conversions per second), it is necessary to change the values of the capacity to 0.1mF. Our realization makes use of both of the mentioned modes of operation, in order to have as precise as possible a test of the suggested digital measuring system. A major influence on the preciseness of the conversion is the precision of the resistor Rint – because of that, we used the laser-trimmed resistor with a mistake of 0.01%.

The complete check of the A/D converter operation, the data collection after the conversion is done, as well as all the necessary re-calculation of the effective voltage, current and active power values – all of it is performed by the standard micro-processor 68HC11 produced by Motorola. This microprocessor is used because of its simplicity and reliability in operation, having in mind the fact that none of the necessary re-calculation is too complicated.

In the solution that is proposed here, a separate circuit is used for **sample and hold**, since the converter described above does not have this circuit integrated in it. As a **sample and hold** circuit, we used the AD684 circuit produced by Analog Devices – a four-channel **sample and hold** amplifier. Two channels were used to measure the signals of the voltage and power, while the remaining two remained unused. This circuit, due to its good characteristics is almost as expensive as the chosen A/D converter. The chosen amplifier requires only 500ns for settings in the hold mode, with the precision of acquisition of 0.01%. It possesses internal condensers and a very low drop-rate (0.01mV/ms). The acquisition time is only 1ms, with a very small **aperture jitter** (75ps) and completely independent inputs, outputs and **sample and hold** control. Owing to the very low impendence, it can used with ultra-fast converters as well.

The block-scheme of the realized digital wattmeter/clock is given in Figure 1.

The supply block that have not been drawn in detail are the standard configurations: 220V/12V transformer with a diode converter and the necessary stabilizers and filter condensers that provide the supply of +- 12V and +5V, the way it is required by the integrating circuits. The part for the adjustment of the voltage and current signal to be processed was done through precise (trimmed) resistors – i.e. the measuring of the current signal is done through precise 'shunt' resistors (this was the the initial solution, although the plate provides for the possibility to use instrumental amplifier with current transformer).

From the figure, it can be noticed that two TC530 converters were used – one to measure the voltage signal, and the other to measure the current signal. The program used for the microprocessor is housed in the outer EEPROM. Next to it, there is a place on the plate which is reserved for the outer RAM, in order to enable the storing of certain data which can be used for the subsequent processing, and also to provide additional memory locations, for the planned re-calculations. Since the device is to be as flexible as possible in relation to the implemented software, it can be supposed that any subsequent modification and the use of a better quality algorithm may require the use of a buffer. The addressing of the perimeters and the memories was done by mapping the address space with the use of the corresponding decoder (PAL circuit).

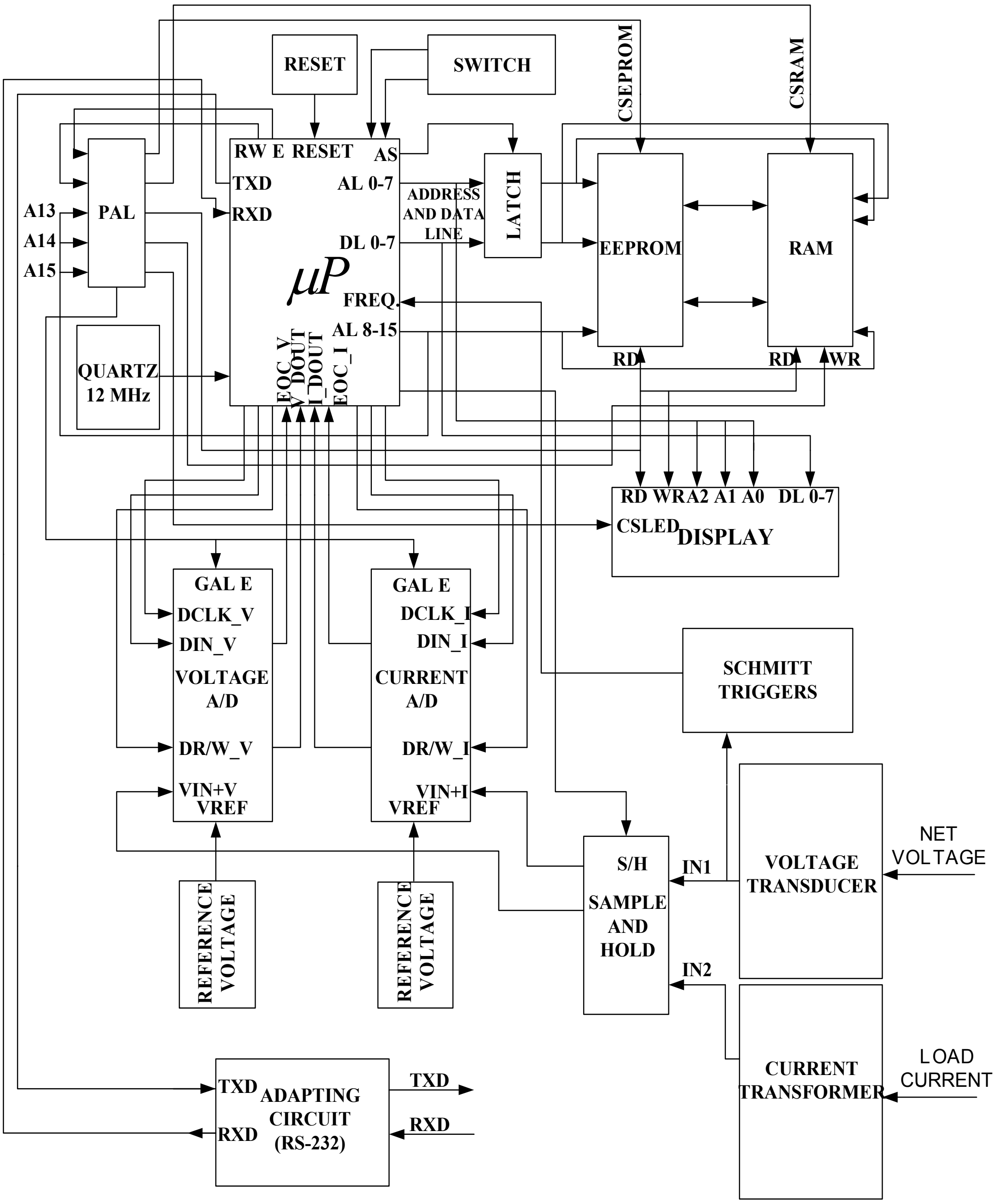

Figure 1-Block-scheme of the realized digital wattmeter.

Through the LED DISPLAY, it is possible to visually monitor the processing results (the calculated effective values of voltage, current or active power in the system) while, by using the adequate push-button, it is possible to select the type of measuring you want. Apart from these basic elements, the plate contains other standard elements such as inter-locking, microprocessor oscillating circuit, etc.

Two of the built-in push-buttons allow the selection of the desired display of the results. By pushing the first push-button, the display will show the effective value of the measured voltage in one column, and the effective value of the current (expressed in Amperes) in the other column. By pushing the second push-button, the display will show the data of the active power at the load (in Watts) and the frequency of the basic harmonic of the voltage signal, expressed in Hertz.

To measure the frequency of the measured signal, we used the comparator which detected the passage of the input sinus (or complex-periodical) signal through the zero; the determining of the current frequency is done by the means of calculating resources of the microprocessor itself. Based on the analysis conducted earlier on in this work, a procedure like this provides completely satisfactory accuracy in establishing the frequency of the measured signal. Apart from this, it is the least demanding solution from the aspect of hardware and software requirements. The circuit with which the frequency of the carrier voltage signal is measured is shown in Figure 2.

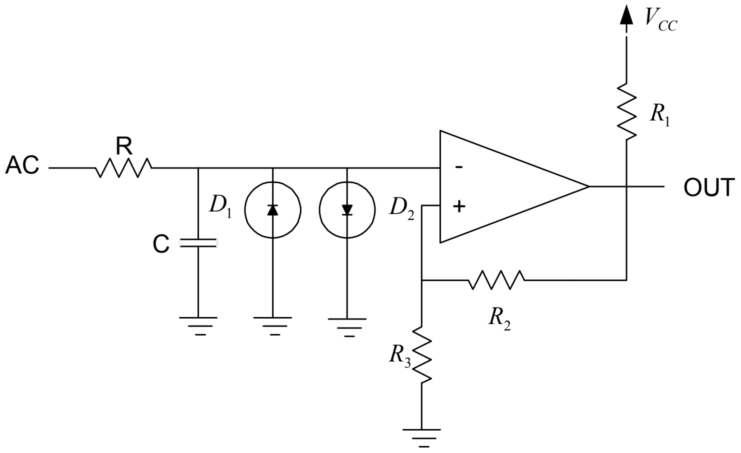

Figure 2-Comparator circuit for measuring of frequency

The comparator circuit detects the passage of the input voltage signal through the zero, so that a line of quadrilateral impulses of the same period is formed, as well as the input sinusoid. The line formed in this way is taken to the microprocessor which, based on the line itself and its own internal pace (12MHz) and the counter, re-calculates the frequency of the carrier signal. Figure 2 shows the input resistor R, with the resistance of 330k, condenser C (capacity – 220pF) and the other values in Picture 4 as follows: R_1=10k, R_2=100k and R_3=1k. The diodes D_1 and D_2 are 1N4148, whereas the power supply V_{CC} is of 12V, brought from the measuring plate itself (where there is a source like this already). This circuit guarantees the precision of 10ppm in the establishing of the carrier signal frequency – more than enough to be applied in the algorithm suggested in this work. The number of the observed signal's passages through the zero (which is obtained by the monitoring of the sign changes in the taken measurings) must be corrected because of the multiple transitions caused by the presence of noise. The interval between the zero passages is checked against the expected frequency of these passages, after which a whole uneven number of the correct zero passages is taken. The frequency of the observed signal is calculated based on the divisor of the time elapsed between the first and the last passage through the zero and the adopted whole (uneven) number of periods.

The voltage signal which is measured can be in the range of 0-400V, whereas the current one is 0 to 10A. The measuring of the current in the outer circuit is done through a current transformer with an operational amplifier in its secondary circuit. This transformer provides it with a practical zero resistance and therefore a better transmission quality. The current transformer is equipped with a 'torus' core made of 'permaloi' and the transition rate 1:2000. this kind of 'torus' core was thoroughly tested in the MINEL laboratory in Belgrade, since this company uses the same cores in their meters. At the test, the core retained very good linearity in the measuring range 0 to 10 A, which absolutely satisfies the demands of the system suggested here. The voltage and the current ranges can be extended through the added potential-meters. It is only important here to that the voltage signals that are brought to the A/D converters through the voltage and current channel are kept within the range of +-2V, in order to preserve the maximum linearity of the applied converter. Through a separately installed potential-meters, the voltage parameter of both channels is adjusted – it can be safely set at 1.025V, in compliance with the manufacturer's recommendations.

The device is connected (through the serial port RS 232) to the PC, for which a special procedure is written, calculating the effective value of the voltage, current and active power. It is also possible to choose the number of the measurings based on which the necessary calculations are done.

The calculation of the observed electrical values was done using this formula:

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\begin{aligned}
U^*_{RMS} &= \sqrt{\frac{1}{W}\sum_{k=1}^{W} u^2\left(k \cdot t_{sampling}\right)} \\
I^*_{RMS} &= \sqrt{\frac{1}{W}\sum_{k=1}^{W} i^2\left(k \cdot t_{sampling}\right)} \\
p^* &= \frac{1}{W}\sum_{k=1}^{W} u\left(k \cdot t_{sampling}\right) i\left(k \cdot t_{sampling}\right)
\end{aligned}
\qquad (2)
$$

where *W* represents the number of the measuring necessary to conduct precise re-calculation (*W*=40, *Δt*=0.5X10-3s). The leap from the one period into another is specified by *N*=6, which results from the speed at which the applied A/D converter operates. During all 6 periods, possible fluctuations in the frequency of the processed signal are monitored, so that these are also taken into consideration in the process of determining the next moment for the measuring of voltage and current signal. The reason why 40 measuring were chosen was in the fact that this was the necessary number of measuring for the most complex harmonic content that can reasonably be expected at the input of the realized digital measuring system [1]. The k index provides the leap from one period to another, whereas the delay *Δt* represents the shift necessary to describe the whole period of the processed values.

The program used to operate the suggested measuring system contains the main program, the sub-programs for testing the correctness of the indicators of the display availability (Busy Flag), for testing the activated push-button, for the initialization of all the memory locations, and for the resetting of the LCD display, a sub-program performing the re-calculation of the basic harmonic frequency, the sub-program which calculates the measured values according to the suggested algorithm.

The device can detect a possible mistake in the transfer of data to the superior PC, based on the implemented CRC (Cyclic Redundancy Check) method. According to the suggested hardware solution, the device itself has an insight into the condition of the controlling lines which participate in the communication of data; however, the device is not supposed to influence their condition or timing – they remain under direct control of the software, which must be implemented in the computer to which such a digital multi-meter can be connected.

In order to eliminate the possibility of error in the re-calculation of the basic electrical values due to an error in establishing the frequency of the carrier signal (which at the realized instrument was 0.02%), the algorithm was adjusted in a way that the number of measuring *W* to be used in the calculation, at the equation (2), is set via the keyboard, prior to the commencement of the operation. The device, based on the set W value performs the re-calculation of the new value of the step *Δt*, where *Δt=T/W*, *T* is the read period of the carrier voltage signal. The device was also tested over a wide frequency range from 46 to 65 Hz, where it retained the expected characteristics.

The algorithms, which were adjusted to the new definition for the effective value of the measured signal (suggested by Professor Miljanic [3]), were also tested. According to this suggestion, the calculation is done based on the set value for the W number of measurings and the equity (1) – however, after this, thus established effective value is used as a border value around which the selection of samples of the processed signal for the following periods is done. This practically means that the first measuring in each next re-calculation of the effective value will be based on the one which is still not bigger than the adopted border value (the effective value of the signal from the first passage). With this approach, the algorithm becomes more resistant to the input error caused by the incorrectly established period of the carrier signal, and the step *Δt* between the two consecutive measurings of the voltage and current signals.

A separate program was written for the Windows environment (in the Visual Basic) in order to open the possibility to inter-connect several of these meters – clocks into a network. In this way, if the developed measuring system is accepted for the monitoring of the real distribution network, we will be in a position to monitor all the relevant parameters: the effective values of current and voltage, power at loaded regime, frequency of the carrier signal and energy. The basic window for this developed application is given in Figure 3.

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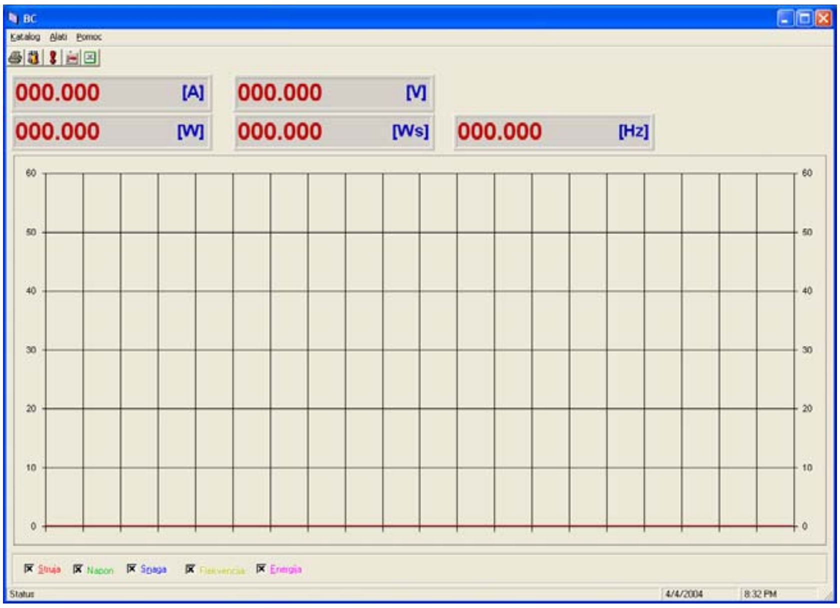
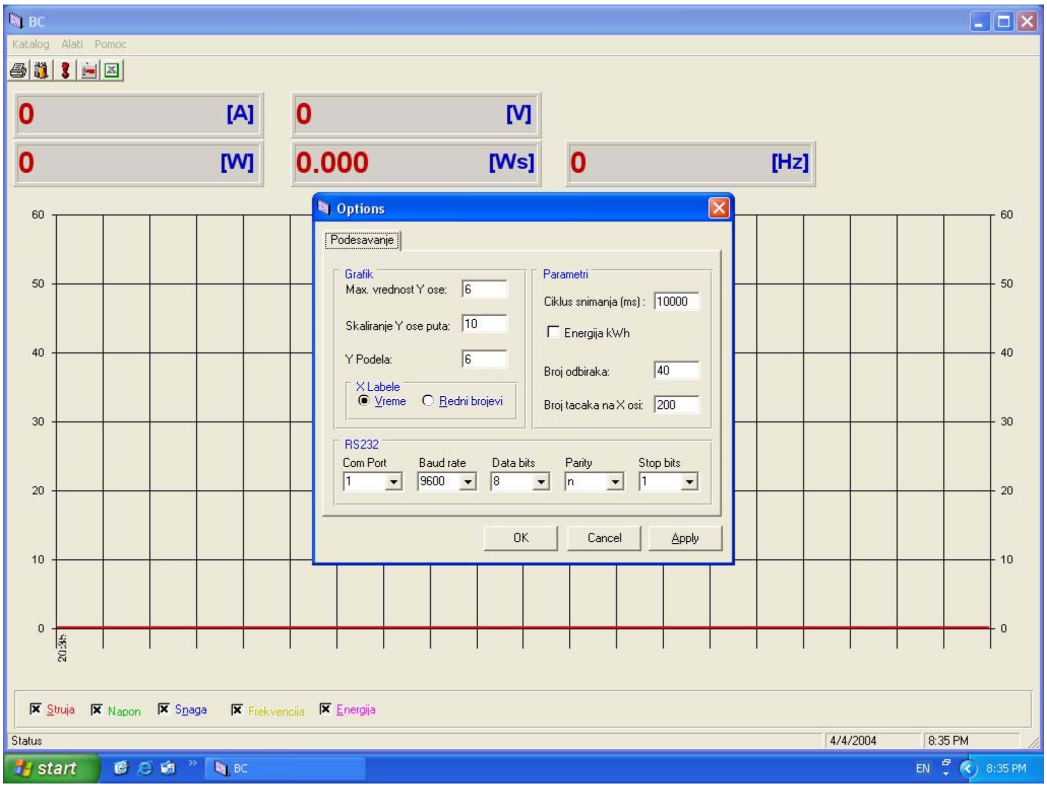


Figure 3-Basic window for monitoring the operation of the realized digital multi-meter.

With this program, each of the operators (the operators can be given different levels of accessibility, depending on the position occupied by the operator in the distribution network) can perform the adjustment of the speed of the transitions of the data series, sent by the realized multi-meter, as well the adjustment of the other parameters in the serial communication. The operator will also be able to change the number of the measurings with which the calculation of the electrical values is done (Figure 4). The measured data can be stored in separate data banks, they can be put in the form of a report in the EXCEL environment, time intervals for which monitoring is required can be set and adjusted, in order to perform a subsequent analysis of the collected data. All of it is accompanied by diagrams for visual monitoring of the measured values.



Grafik
Max. vrednost Y ose: 6
Skaliranje Y ose puta: 10
Y Podela: 6
X Labele: ● Vreme ○ Redni brojevi

Parametri
Ciklus snimanja (ms) : 10000
☐ Energija kWh
Broj odbiraka: 40
Broj tacaka na X osi: 200

RS232
Com Port: 1
Baud rate: 9600
Data bits: 8
Parity: n
Stop bits: 1

Figure 4-Window for adjustment of the serial communication parameters.

RESULTS OF PRACTICAL MEASURINGS WITH THE REALIZED DIGITAL WATTMETER/ WATTHOURMETER

In order to perform testing of the realized device, measurings were conducted in the Laboratory for Electrical Measurings at the Technical Faculty of Novi Sad, at the high precision calibrator [4]. This calibrator has the voltage output of up to 120V and the current output of 10A. The conducted check produced the following results:

RMS value of voltage	RMS value of current	Active power	number of samples
114.1806	3.981788	454.3577	80
114.0674	3.981969	453.9036	160
114.2801	3.978548	454.369	240
114.1484	3.983826	454.4442	320
114.0759	3.972872	452.9076	400
114.1127	3.981742	454.0458	480
114.122	3.978764	453.7419	560
114.1166	3.973524	453.1388	640
114.1363	3.979644	453.9105	720
114.1472	3.983184	454.3487	800
114.1599	3.982001	454.2574	880
114.121	3.981494	454.0564	960
114.1734	3.981692	454.2896	1040
114.0864	3.976552	453.3707	1120
114.1897	3.980685	454.2383	1200
114.2198	3.988401	455.2225	1280
114.3225	3.991148	455.999	1360
114.2734	3.983006	454.8303	1440
114.3343	3.994197	456.4182	1520
114.3372	3.986395	455.5184	1600

RMS value of voltage	RMS value of current	Active power	number of samples
114.42768	4.005491	457.433	40
114.7128	4.00211	458.851	80
114.8063	4.006526	459.6562	120
114.7667	3.996995	458.441	160
114.7612	4.00658	459.5241	200
114.7581	4.000422	458.8007	240
114.735	3.998314	458.5224	280
114.6297	3.995979	457.7766	320
114.8738	4.007427	460.0301	360
114.8007	4.000439	459.0017	400
114.58	4.001225	458.1579	440
114.7051	4.006862	459.2712	480
114.5404	4.007206	458.7236	520
114.6315	4.000561	458.2874	560
114.5807	3.997463	457.7387	600
114.6943	4.00513	459.0651	640
114.5405	3.994595	457.2853	680
114.6369	3.996784	457.8522	720
114.6104	3.996654	457.7787	760
114.6999	4.005065	459.0636	800

TABLE 1-The results of measuring at the calibrator, at the frequency of a) 50Hz and b) 53Hz

By a subsequent analysis of the obtained results, the possible sources of the error were revealed. The existing hardware was re-adjusted accordingly, in order to eliminate the flows. There are already certain indicators that a device can be expected that will operate in the class 0.1.

CONCLUSION

The design of the digital measuring system based on the use of highly precise A/D dual slope converters was put into practice, on which occasion two such converters were used, one for measuring the voltage signal and the other for measuring the signal of the current. The compete control over the operation and all the necessary calculations are performed by a general purpose micro-processor (Motorola 68HC11). With its current characteristics, the device belongs to the class 0.15 instruments. There is a possibility to further on optimize the existing technical solution, in order to reduce the price of the final instrument, and to improve its precision. All of the exposed data and the results create a base for the development of highly-precise instruments (class 0.1) which can be used for reference and laboratory measurings, or for a real system measurings, with which it is possible to reduce the requirements for the necessary resolution of a digital system.

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